TRAFFICABILITY TESTS WITH THE 5-TON GOER (XM520) ON FINE-AND COARSE-GRAINED SOILS

MISCELLANEOUS PAPER NO. 4-477

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U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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Preface

The trafficability tests with the 5-ton GOER 4x4 cargo carrier reported herein were made to obtain information for use in furtherance of Corps of Engineers Project 8S70-05-001-02, Surface Mobility. They were conducted at Vicksburg, Miss., during the period 18 January-23 February 1961, by personnel of the Army Mobility Research Center, U. S. Army Engineer Waterways Experiment Station, under general supervision of Messrs. W. J. Turnbull, Chief of Soils Division; S. J. Knight, Chief of Army Mobility Research Center; and A. A. Rula, Chief of Trafficability Section. Mr. E. S. Rush of the Trafficability Section supervised the field tests and prepared this report.

Acknowledgment is made to the Clark Equipment Company of Benton Harbor, Mich., for the loan of a set of 15.00-34 tires and wheels for testing on the GOER, and to U. S. Army Armor Board, U. S. Army Ordnance Tank-Automotive Command (particularly Capt. E. L. Birk), for arranging transfer of the vehicle to WES.

Col. Edmund H. Lang, CE, was Director of the Waterways Experiment Station during the field testing, and Col. Alex G. Sutton, Jr., CE, was Director during preparation of this report. Mr. J. B. Tiffany was Technical Director.

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Summary

Trafficability tests were conducted in soft, fine-grained soils and clean sand to determine the performance characteristics of the 5-ton GOER XM520 4x4 cargo carrier for two tire sizes. The minimum soil strength required for 50 passes of the vehicle (vehicle cone index), with two different sets of tires, was determined experimentally in fine-grained soils and compared with computed vehicle cone indexes. The GOER operated in a lower strength of soil (fine-grained) with 18.00-26 tires than with 15.00-34 tires. The experimental vehicle cone index was 3 units higher than the computed vehicle cone index (57 vs 54) with the 18.00-26 tires and 7 units higher (63 vs 56) with the 15.00-34 tires. The vehicle cone indexes for the GOER were lower than those for standard military 6x6 trucks of 2-1/2- to 5-ton capacity (65 to 75). In clean sands, the GOER was able to develop higher drawbar pulls when equipped with the 18.00-26 tires than with the 15.00-34 tires (on the same strength of soil) and with both tires developed higher tractive coefficient (drawbar/weight) than any military wheeled vehicle tested thus far. Additional tests of the GOER in snow, sand, and muskeg are recommended to evaluate the vehicle further. Tests of the 15-ton GOER are also recommended. The computations for determining the mobility index and vehicle cone index of the GOER for operation in fine-grained soils are presented in Appendix A.

TRAFFICABILITY TESTS WITH THE 5-TON GOER (XM520) ON FINE- AND COARSE-GRAINED SOILS

Introduction

1. The GOER* family of vehicles is a new and experimental concept of military wheeled vehicles designed especially for cross-country travel and intended to replace existing military cargo and supply trucks of 2-1/2-ton and greater capacity. In view of the possible acceptance of the GOER concept by the military, the Office, Chief of Engineers, directed that the Army Mobility Research Center of the U. S. Army Engineer Waterways Experiment Station conduct tests to determine the off-road performance of a 5-ton GOER and report the findings.

The Vehicle

2. Two views of the 5-ton GOER (XM520) 4x4 cargo carrier are shown in fig. 1. The GOER encompasses some of the design features of earth-moving and construction-equipment vehicles. The main design features, all

a. Front view

b. Side view

Fig. 1. 5-ton GOER, 18.00-26 10-PR tires

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* The term "GOER" was coined and initiated by the U. S. Army Armor Board, Fort Knox, Kentucky, and has been informally adopted to describe this type of military wheeled vehicle.

of which are intended to increase GOER mobility over that of more conventional wheeled vehicles, are: (a) large diameter, low-inflation-pressure tires; (b) powered wagon steering; (c) exoskeletal construction; (d) no suspension system; (e) ratio of payload to gross vehicle weight of about 50%; and (f) inherent floatability. The GOER concept is also incorporated into a 15-ton-capacity vehicle with similar design features.

3. Pertinent vehicle data for the 5-ton GOER tested are:

		Empty	Loaded
Vehicle weight, lb		16,530	26,667
Front axle		11,995	14,358
Rear axle		4,535	12,309
Engine horsepower		110	
Transmission		Torque converter	
Tires: Type		Construction-equipment, diagonal tread	
Sizes		18.00-26 10-PR	15.00-34 10-PR
Total contact area, sq in.*:			
At 30-psi inflation pressure		1241	1086
At 20-psi inflation pressure		1465	1259
At 15-psi inflation pressure		1605	1423
At 10-psi inflation pressure		1892	1778
Ground clearance, in.		21	22
Computed vehicle cone index (VCI)		53	55

* From contact prints made on a hard surface, gross weight 26,667 lb.

Purpose and Scope of Test Program

4. The purpose of the test program reported herein was to determine the performance of the GOER on fine- and coarse-grained soils. Two tire sizes were used for tests on both types of soil. The GOER's performance on fine-grained soils, measured in terms of minimum soil strength in the critical layer† required for 50 passes of the vehicle (vehicle cone index), was compared with its computed performance derived from the formula (see

† For wheeled vehicles of up to 50,000-lb gross weight, the 6- to 12-in. layer is considered the critical layer in fine-grained soils, and the 0- to 6-in. layer is considered critical in clean sands.

Appendix A) for determining the mobility index of wheeled vehicles on fine-grained soils.* GOER performance on coarse-grained soil (clean sand), measured in terms of maximum drawbar pull, force required to tow, and soil strength in the critical layer was determined for four tire-inflation pressures and compared with the performance of other wheeled and tracked vehicles.

Test Areas and Soil Properties

Test areas

5. The four test areas used in the investigation were located near Vicksburg, Miss.: (a) on WES grounds, (b) adjacent to the Yazoo Canal, (c) near the Port of Vicksburg, and (d) on a Mississippi River beach near the Vicksburg Bridge. Locations of the test areas are shown in fig. 2, and views of portions of the areas are shown in fig. 3.

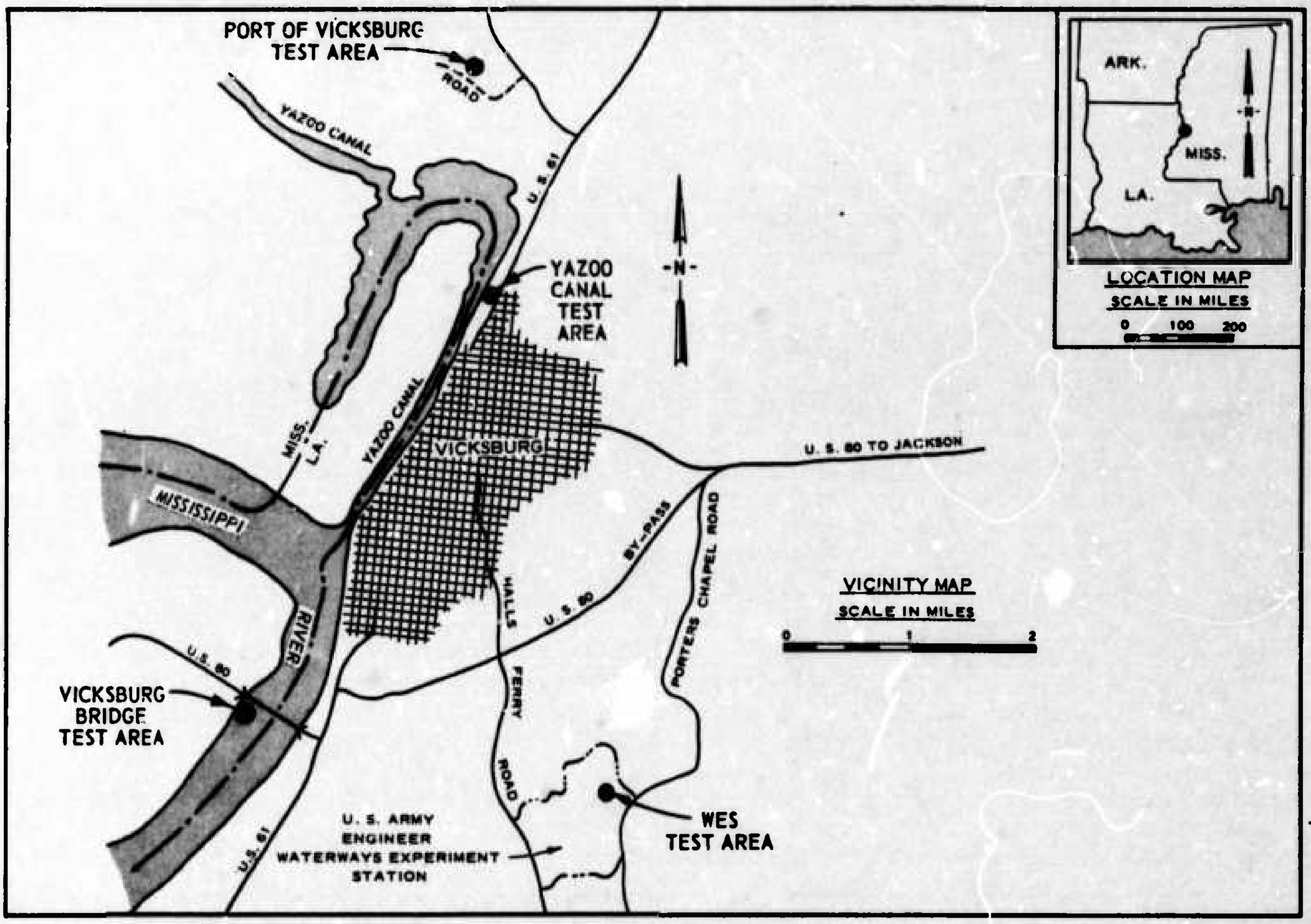


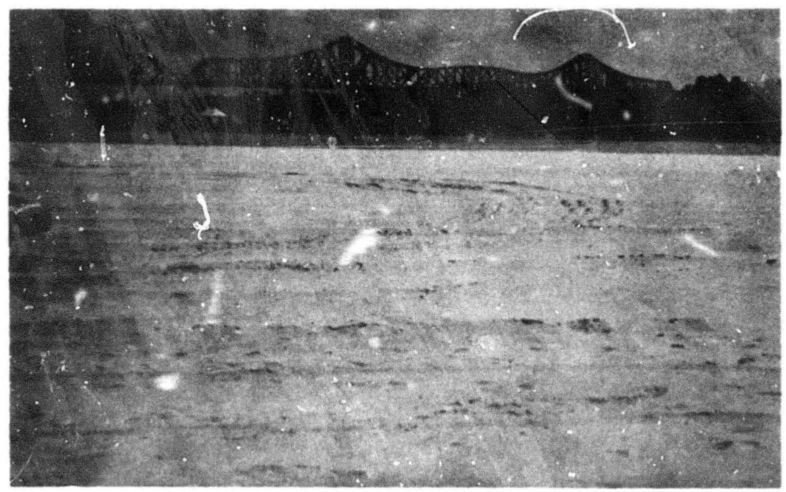
Fig. 2. Location of test areas, Vicksburg, Miss.

* U. S. Army Engineer Waterways Experiment Station, CE, Trafficability of Soils, A Summary of Trafficability Studies Through 1955, Technical Memorandum No. 3-240, 14th Supplement (Vicksburg, Miss., December 1956).

a. On WES grounds

b. Adjacent to Yazoo Canal

c. Near Port of Vicksburg

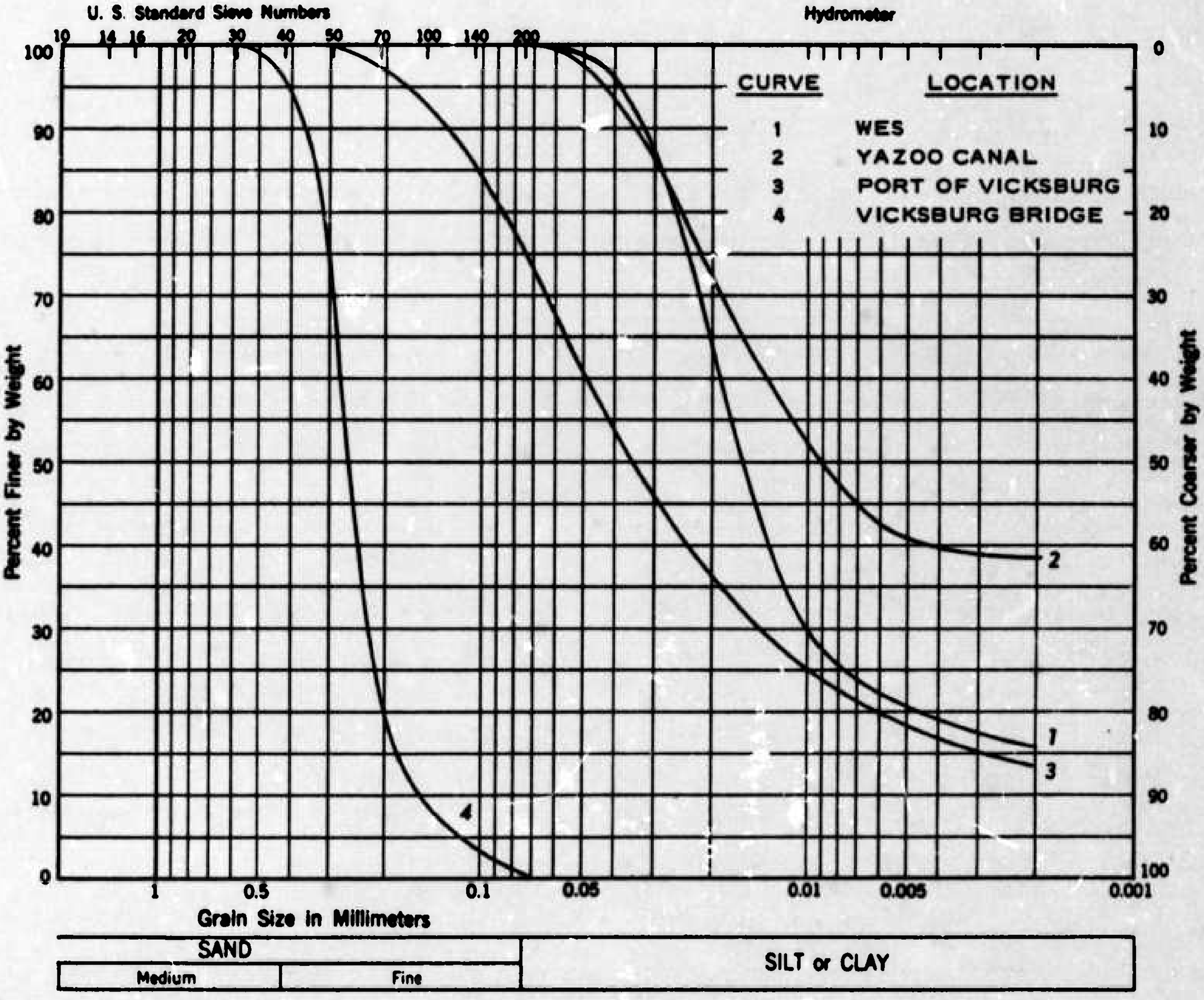


d. Near Vicksburg Bridge

Fig. 3. Test areas

Soils

6. At WES, tests were conducted in a level bottomland area of silt washed down from surrounding loessial hills. On the bank of the Yazoo Canal, tests were conducted in level, silty clay soil deposited by overflow from the canal. At the Port of Vicksburg one test was conducted in soft, sandy clay soil in a filled borrow pit. Tests near the Vicksburg Bridge were performed on clean sand on a beach area exposed during low river stages. Gradation curves and supplementary soils data are shown in fig. 4.



Number	Depth, in.	Natural Moisture	L. L.	P. L.	P. I.	Classification
1	6-12		40	27	13	SILT (ML)
2	6-12		53	23	30	SILTY CLAY (CH)
3	6-12		32	22	10	SANDY CLAY (CL)
4	0-6				NP	UNIFORM FINE SAND (SP)

Fig. 4. Gradation curves and supplementary soils data

Test Procedures and Data

7. Self-propelled tests were conducted in fine-grained soils and maximum drawbar-pull and towed tests were conducted in coarse-grained soils.

Self-propelled tests

8. Thirty-three tests were conducted at the three fine-grained soil test areas by running the vehicle back and forth in a 100-ft-long path, selected for each test, until it became immobilized or had completed 50 passes and immobilization did not seem imminent. The vehicle was operated in lowest gear with all wheels driving at a speed of approximately 2 mph; tire pressure was 18 psi for all these tests, in 17 of which the 18.00-26 tires were used, and in 16 the 15.00-34 tires were used. At the beginning of each test the 100-ft-long test lane was staked out, and the cone index* of the soil was measured at 10-ft intervals along the proposed center line of each rut. At each point measurements were made at the surface and at 3-in. vertical increments to a depth of 30 in. Two remolding index* tests, one for each track of the vehicle, were made on soil samples taken from the 6- to 12-in. depth near the point where the lowest cone index was measured. Soil samples for moisture content and density determinations were taken from the 6- to 12-in. depths at each remolding index station. Rut depth and cone index of the soil in the ruts were measured at varying intervals during the course of the test. Observations were made of the behavior of the soil and vehicle during each test. Data and test results are summarized in table 1.

Maximum drawbar-pull tests

9. Forty-nine tests were conducted in clean sand, 23 with the 18.00-26 tires and 26 with the 15.00-34 tires. Because immobilizations due to sinkage, such as occur in fine-grained soils, do not normally occur in clean sand, evaluation of vehicle performance was made by determining the maximum sustained drawbar pull the GOER could develop. Maximum drawbar-pull tests were performed on level sand with the GOER towing a load vehicle by means of a cable. As the vehicles moved forward in a straight-line path at about 2 mph, the pull of the GOER was gradually increased (by

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* Defined in WES TM 3-240, 14th Supplement.

application of the brakes on the load vehicle) until a load condition was established that was slightly less than that which would cause the GOER to become immobilized. Continuous inked records of drawbar pull were obtained by means of necessary electric and electronic equipment. Soil data were collected in the areas of maximum drawbar pull after completion of each test. These data consisted of cone index, moisture content, and density determinations made outside the zone of disturbance by the vehicle, and are considered to be "before-traffic" data for analysis purposes. A set of cone index readings consisted of measurements made at the surface and at 3-in. vertical increments to a depth of 18 in. or to a depth at which the capacity of the cone penetrometer (300) was reached. Ten sets of cone index readings usually were made for each test, five on each side of the test lane. Tire-inflation pressures were measured carefully before each test. The data and test results are summarized in table 2.

Towed tests

10. Towed tests were conducted in coarse-grained soil along with the maximum drawbar-pull tests. The soil property measurements made for the drawbar-pull tests are also applicable to the towed tests. Continuous inked records of the force required to tow the GOER at speeds from 1 to 2 mph were obtained in the same manner as in the towing tests.

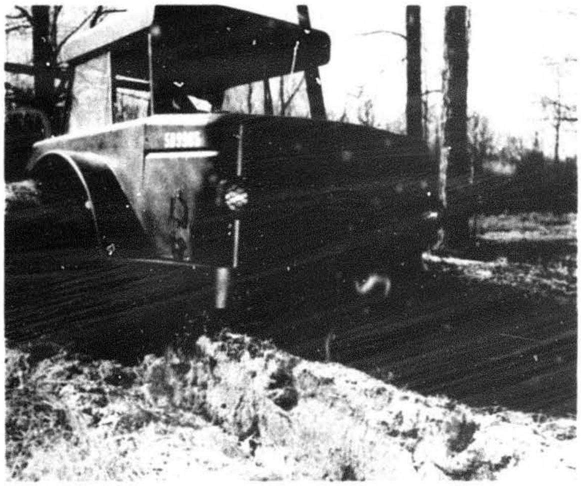
Test Results

Self-propelled tests

11. Trafficability tests in fine-grained soils normally follow a pattern of increased rutting of the soil by the wheels or tracks with increased number of passes over the test lane. If the soil is soft, deep ruts occur after only a few passes; if the soil is firmer, deep ruts will occur only after numerous passes. In any event, once rutting has progressed to where the undercarriage drags, vehicle passage is labored and immobilization may be expected. Fig. 5 shows a sequence of rutting and eventual immobilization for a typical test.

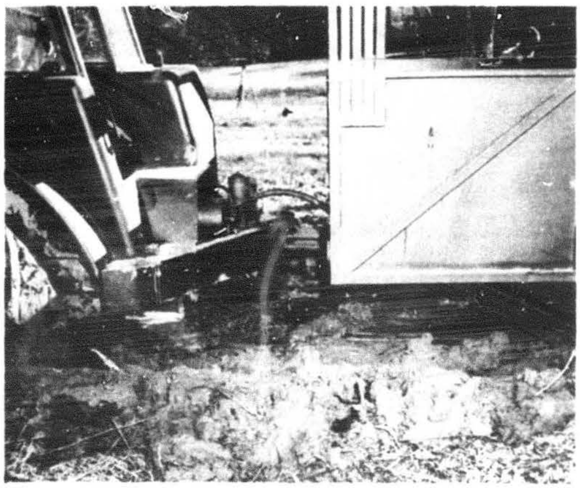
12. The principal purpose of the tests conducted in silt and clay was to determine experimentally the vehicle cone index (VCI) of the GOER and compare it with the computed VCI. The VCI is the minimum rating cone

a. Test lane after one pass



d. Front view, GOER after 10th pass immobilization

b. Test lane after 5 passes



e. Side view, GOER after 10th pass immobilization

c. Rear view, GOER after 10th pass immobilization

Fig. 5. Sequence of rutting and eventual immobilization, test 2 (see table 1)

index required for a vehicle to negotiate 40 to 50 passes in a straight-line path. The VCI computations for the GOER are given in Appendix A.

13. Determination of experimental VCI. The VCI of the GOER for each of the two tire sizes was determined as described in the following subparagraphs.

a. Tests with 18.00-26 tires. Test data are summarized in table 1 (tests 1-17) and are shown graphically in fig. 6.

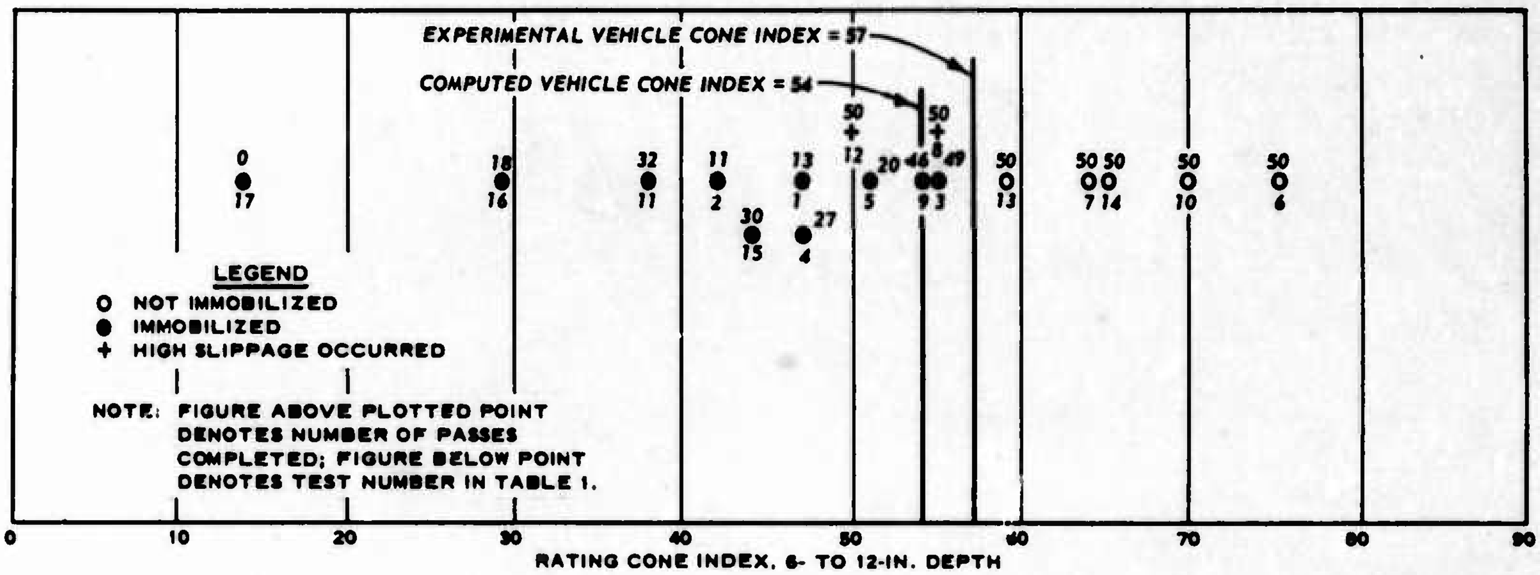


Fig. 6. Vehicle performance, tests in fine-grained soil, 18.00-26 10-PR tires

The experimental VCI line separates immobilizations from nonimmobilizations. Ten tests resulted in immobilizations. Two of the nonimmobilization tests plot to the left of the line, but in these tests the vehicle was experiencing difficulty because of high slip on the last passes. These two tests are identified by "crosses" on the data plot. Immobilizations occurred in all three soils tested; the most severe immobilization occurred on the first pass in test 17 on sandy clay which had an initial high cone index of 113 but a very low remolding index of 0.12. From fig. 6 it can be seen that a line drawn at a rating cone index (RCI) of 57 separates the immobilizations (and two tests with high slip) from the nonimmobilizations. From these data, the experimental VCI for the GOER with 18.00-26 tires is thus 57. Fig. 7 (page 10) shows the one-pass rut pattern and the immobilized vehicle.

b. Tests with the 15.00-34 tires. Test data are summarized in table 1 (tests 18-33) and are shown graphically in fig. 8. The experimental VCI line separates immobilizations from nonimmobilizations. Seven of the 16 tests conducted were immobilizations, and for two of the nonimmobilizations the vehicle was experiencing high slip on the last passes

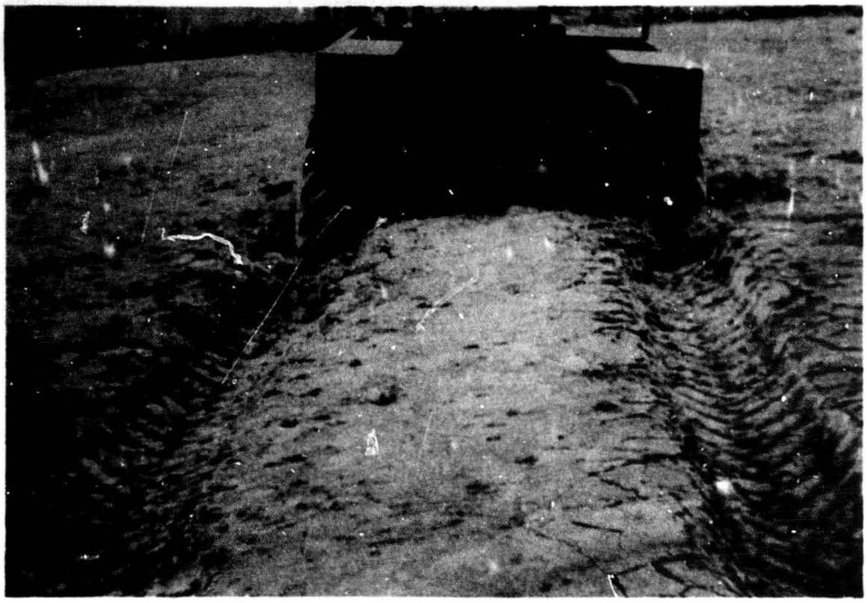


Fig. 7. Immobilization on 1st pass; test 17, table 1

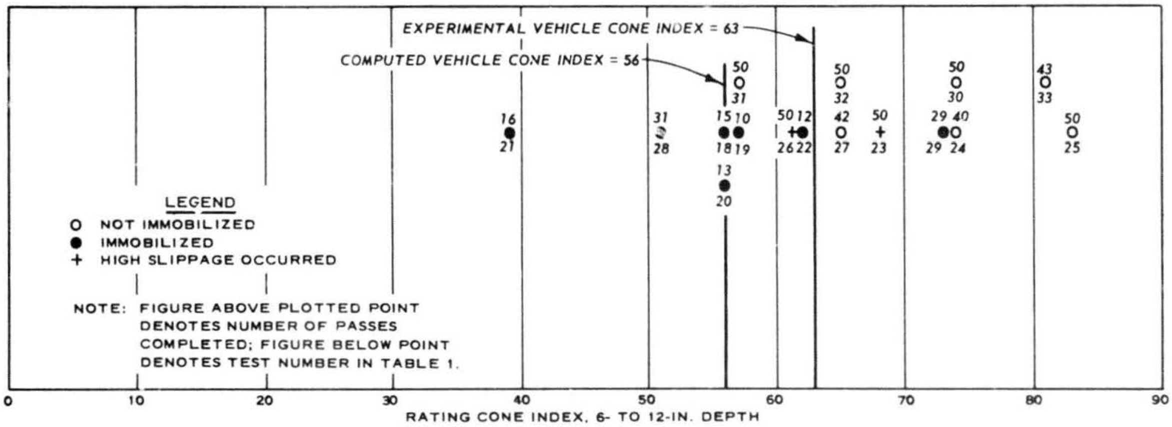


Fig. 8. Vehicle performance, tests in fine-grained soil, 15.00-34 10-PR tires

although it completed 50 passes. These tests are identified by crosses in the data plot. It can be seen in fig. 8 that the experimental VCI has been drawn at an RCI of 63. Test 29 plots to the right of the line; however, in this test the vehicle became immobilized because of slipperiness which became excessive as a result of free water draining into the ruts (see fig. 9). Test data do not indicate why test 31 is a nonimmobilization. The experimental VCI for the GOER with 15.00-34 tires has thus been established at 63.

14. Comparison of experimental and computed VCI's. From figs. 6 and 8, it can be seen that the experimental VCI was higher than the computed VCI, three units higher for the GOER with 18.00-26 tires and seven units higher for the GOER with 15.00-34 tires. In tests conducted with the Jumbo

Fig. 9. Immobilization due to slipperiness on 30th pass; test 29, table 1

truck* and the Tournadozer, two vehicles which are also equipped with larger tires than those used in developing the formula for VCI, a similar relation between experimental and computed VCI's also was found. In the case of these two, it was hypothesized that their wide, flat bottoms contributed to an earlier immobilization (smaller number of passes) than would have occurred had the bottoms of the vehicles not been covered with a wide, flat plate. With this in mind, an arbitrary number of passes completed, 25 (instead of the 50 passes used in the original tests to develop the formula for VCI), was selected as a division point between immobilizations and nonimmobilizations. When the data were re-examined on this basis, the experimental and computed VCI's approximated each other very closely. The GOER, too, has a wide, flat bottom plate and the same reasoning applied to it results in closer agreement of experimental and computed VCI's in the case of the 18.00-26 tires, but does not significantly affect the relation of the VCI's in the case of the 15.00-34 tires. From this evidence, it would appear that wide, flat bottoms have a detrimental effect on the performance of wheeled vehicles in soft soil, but the evidence is not absolutely conclusive, and it very well may be that the formula for computing VCI's needs some revision to increase its accuracy when applied to vehicles with large tires. The point is mainly academic

* U. S. Army Engineer Waterways Experiment Station, CE, Trafficability Tests with Jumbo Truck on Organic and Coarse-Grained Mineral Soils, Miscellaneous Paper No. 4-438 (Vicksburg, Miss., July 1961).

since the difference between experimental and computed VCI's, wide pan effects discounted, is only in the order of a few units. Nevertheless, it is considered worthwhile to determine the applicability of the formula and the effect of wide, flat pans by further testing.

15. For both tire sizes the experimental VCI's are higher than the computed VCI's, but it is also interesting that both the experimental and computed VCI's of the GOER with 18.00-26 tires are lower than the respective VCI's with 15.00-34 tires. In other words, the GOER performs better in fine-grained soils with 18.00-26 tires than it does with 15.00-34 tires.

16. Comparison of GOER experimental VCI with VCI's of standard 6x6 military trucks. The GOER experimental VCI of 57 (with 18.00-26 tires) is lower than that of other wheeled vehicles in the military system of approximately the same payload rating. This may be verified by inspection of the VCI's listed in Appendix A, TM 3-240, 14th Supplement.* Vehicles of comparable gross weights usually are 6x6's, such as the M41 5-ton cargo trucks which have a VCI of 66. Some 2-1/2-ton cargo trucks have VCI's as low as 60 to 62; however, their gross weights are seldom over 18,000 lb. Ratios of payload to gross vehicle weight are approximately 60% for the GOER, 53% for the M41 5-ton truck, and 40% for the 2-1/2-ton trucks.

Maximum drawbar-pull tests

17. These tests were conducted to determine the maximum drawbar pull of the GOER equipped first with 18.00-26 10-PR tires and next with 15.00-34 10-PR tires at inflation pressures of 30, 20, 15, and 10 psi. Fig. 10 shows a test in progress in sand.

Fig. 10. Typical maximum drawbar-pull test in clean sand

* Reference cited on page 3.

18. Tests with 18.00-26 tires. Results of the tests conducted with these tires are summarized in table 2 (tests 1-23) and shown graphically (cone index vs maximum drawbar pull) in fig. 11. Although the range of cone index tested was narrow, there appears to be a general trend of increase in maximum drawbar pull with increase in cone index. Performance curves were drawn through the plotted points of each tire pressure; the shape of these curves was influenced somewhat by shape of similar curves for other vehicle test results over a much wider range of cone index.* For easier comparison of performance, since the range of cone index and drawbar pull for a given tire pressure was small, test results were averaged and summarized as follows:

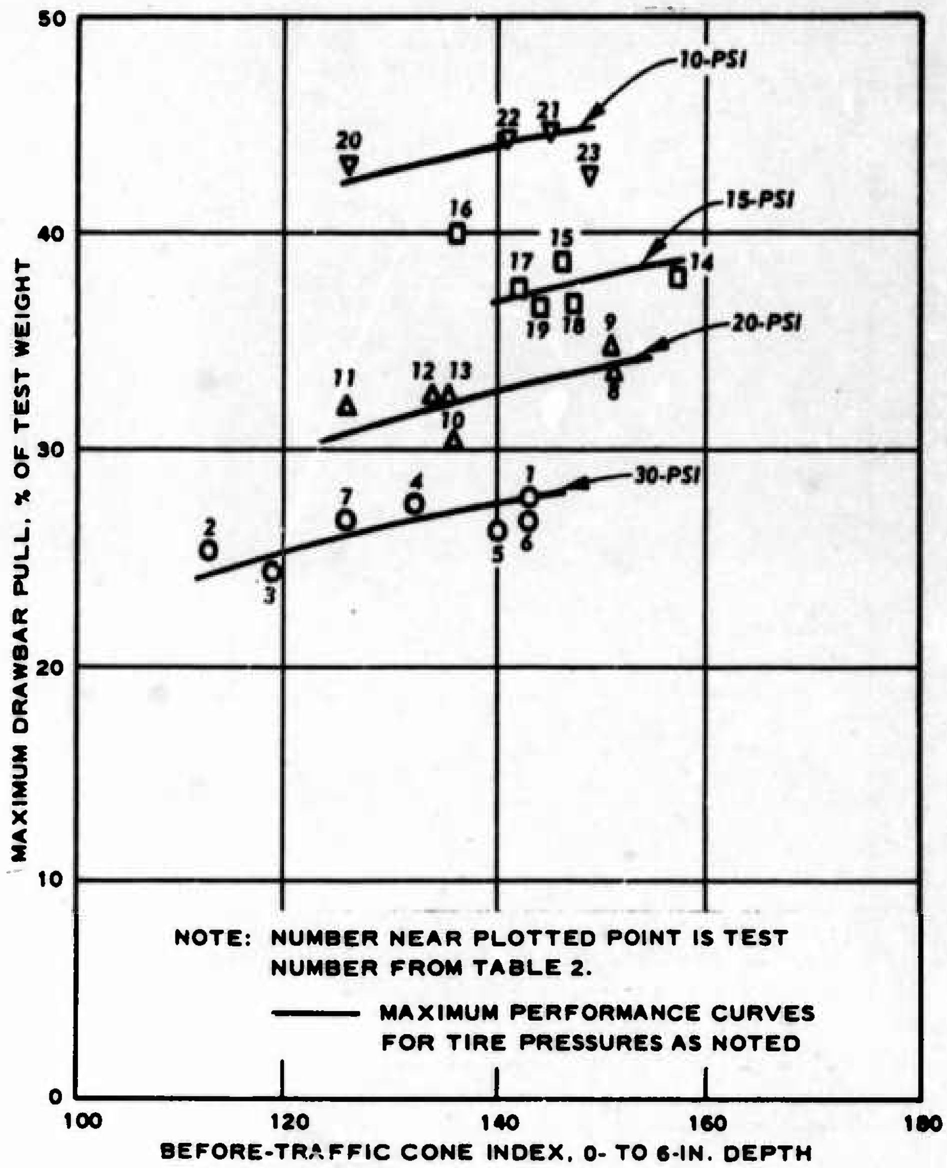


Fig. 11. Vehicle performance in clean sand, 18.00-26 10-PR tires

Tire Pressure, psi	Average Maximum Drawbar Pull % of Test Weight	Average Cone Index 0- to 6-in. Depth
30	26.3	131
20	32.6	139
15	37.9	145
10	43.8	140

19. This tabulation shows increases in maximum drawbar pull with

* U. S. Army Engineer Waterways Experiment Station, CE, Trafficability of Soils, Tests on Coarse-Grained Soils with Self-propelled Wheeled and Tracked Vehicles, November 1958-February 1961, Technical Memorandum No. 3-240, 17th Supplement (Vicksburg, Miss., unpublished).

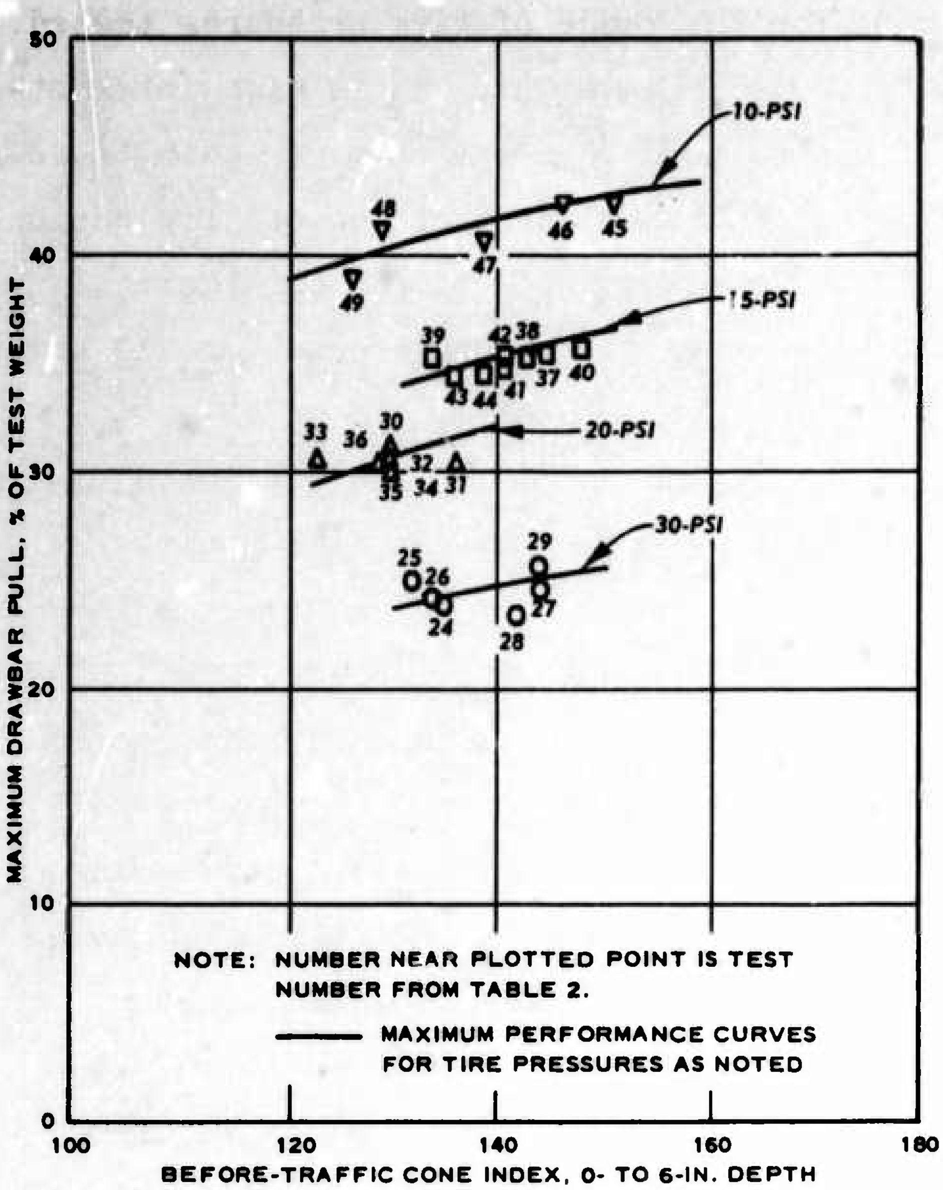


Fig. 12. Vehicle performance in clean sand, 15.00-34 10-PR tires

decreases in tire pressure with little difference in cone index. An average maximum drawbar pull of 43.8% at 10-psi tire pressure indicates good performance. A comparison of GOER performance with performance of other vehicles is presented in paragraph 23.

20. Tests with 15.00-34 tires. Results of tests conducted with these tires are summarized in table 2 (tests 24-49) and shown graphically (cone index vs maximum drawbar pull) in fig. 12. As for the tests with the 18.00-26 tires, the range of cone index was narrow, and for comparison purposes cone index and drawbar pull were averaged for each tire pressure as follows.

Tire Pressure, psi	Average Maximum Drawbar Pull % of Test Weight	Average Cone Index 0- to 6-in. Depth
30	24.5	139
20	30.7	130
15	35.3	141
10	41.2	138

21. As can be seen here, there is an orderly progression of increased drawbar pull with decreased tire pressure. Comparisons of tire sizes with respect to performance are discussed in the following paragraph.

22. Comparison of GOER performance with 18.00-26 tires and with 15.00-34 tires. The two tabulations in the preceding paragraphs show that the GOER has consistently higher drawbar pulls with the 18.00-26 10-PR

tires than with the 15.00-34 tires, for the range of tire pressures tested. The difference is approximately 2% of vehicle weight. It is also interesting to note that contact areas of the 18.00-26 tires are larger than those of the 15.00-34 tires at equal tire pressures. Observations of tire action during the tests revealed that the 15.00-34 tires developed considerable sidewall buckling at 10 psi for high drawbar pulls, and probably would have been permanently damaged if operated for any length of time at this tire pressure. The 18.00-26 tires at 10 psi, although bulging along the sidewalls, did not buckle and could probably have been operated at 5 psi without harmful results.

23. Comparison of GOER performance with other vehicles. Tests have been conducted on clean sand with a range of military wheeled and tracked vehicles to determine their performance (in terms of maximum drawbar pull) for a range of sand strengths.* A comparison was made of the performance of the GOER for two tire sizes with that of an M41 6x6 5-ton truck, having 14.00-20 12-PR tires, and also with that of an M5A4 high-speed tractor. All vehicles were in the same general weight class, 25,230 to 26,667 lb. Performance at 10-psi tire pressure only was considered for the wheeled vehicles. These comparisons are shown graphically in fig. 13. As can be

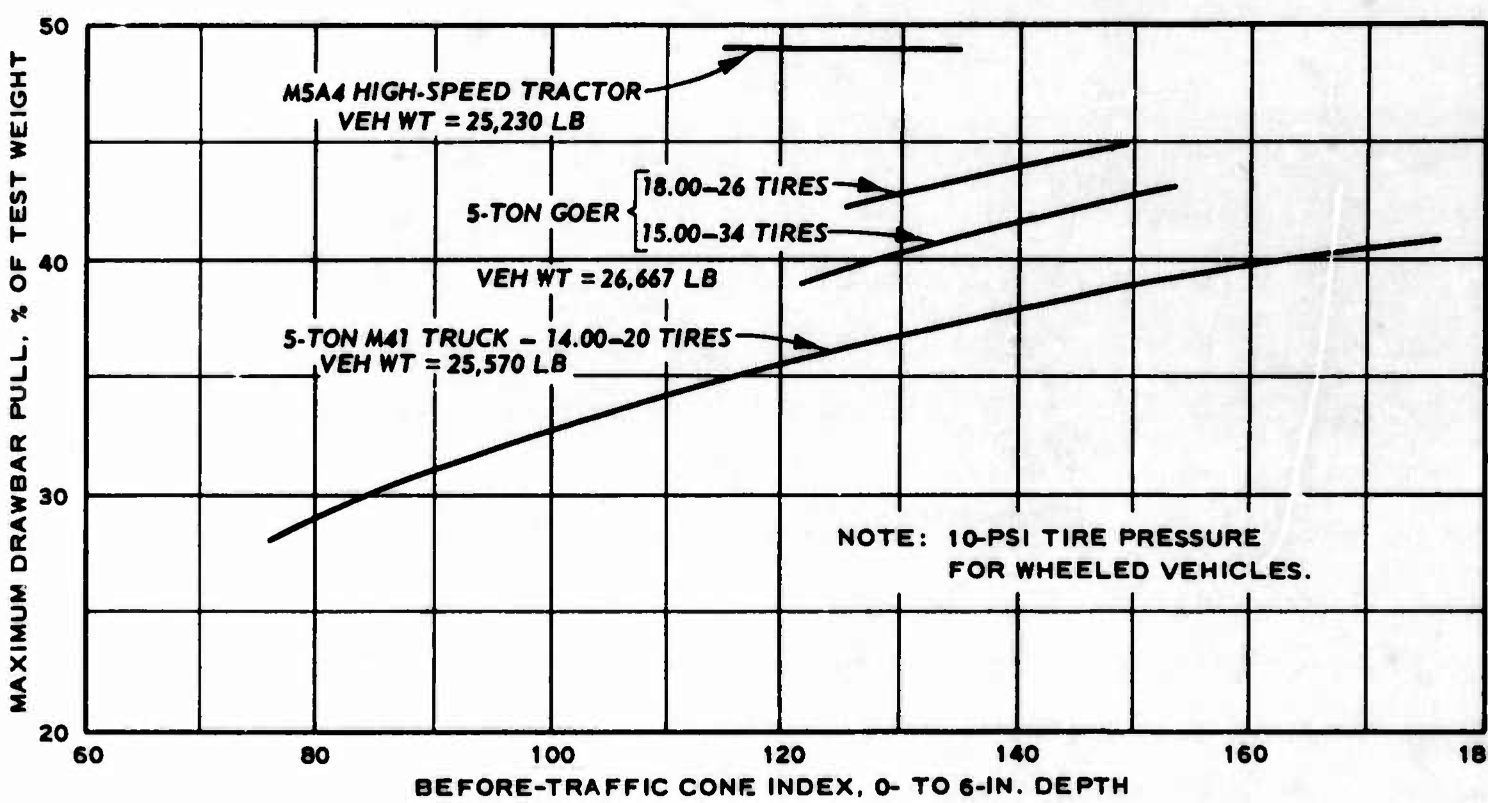


Fig. 13. Comparison of GOER performance with that of other vehicles on clean sand

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* Reference cited on page 13.

seen in fig. 13, at equal cone indexes the GOER (18.00-26 tires) developed approximately 6% greater drawbar pull than the M41 and approximately 6% less drawbar pull than the M5A4 tractor. The GOER appears to perform better than other wheeled vehicles tested thus far, but not as well as most tracked vehicles since the M5A4's performance is poorer than that of other tracked vehicles such as the engineer tractors.

Towed tests

24. Limited towed tests were conducted to determine the amount of force required to tow the GOER equipped first with 18.00-26 tires and next with 15.00-34 tires at inflation pressures of 30, 20, and 15 psi. The following tabulation summarizes results of tests:

Tire Inflation Pressure, psi	Towing Force Required % of Test Weight	Average Cone Index 0- to 6-in. Depth
	18.00-26 tires	
30	6.5	126
20	5.6	135
15	5.2	144
	15.00-34 Tires	
30	5.6	144
20	5.9	129
15	5.5	139

25. Examination of the above tabulation shows a trend of decrease in towing force required with a decrease in tire pressure, if cognizance is taken of differences in cone index, i.e. if the cone index for tests with the 15.00-34 tires at 20 psi was as high as for tests at 30 and 15 psi, then the towing force required would probably have been in the order of 5.6 to 5.5% instead of 5.9%. While the results of these limited tests do not demonstrate clearly which tire size offers the lesser resistance to being towed, they do indicate that the force required to tow the GOER, in terms of percentage of vehicle weight, is less than that of standard military trucks at the same tire pressure and cone indexes. Military trucks have been found to require a towing force of approximately 6 to 8%.* The reasons for the apparent superiority of the GOER over standard military trucks are currently being studied.

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* Reference cited on page 13.

Notes and Observations Made During Tests

Lack of adequate torque

26. During the later passes of 50-pass tests in fine-grained soils when the GOER undercarriage was dragging, the torque applied to the wheels was, on occasion, not enough to spin them. This deficiency was apparently caused by overheating of the torque converter due to prolonged operation where torque requirements were great. For tests when the undercarriage began dragging early--during the first 10 to 15 passes--the GOER had adequate torque to spin its wheels. It is understood that this deficiency is not found in all GOER's.

Cleaning ability of tires

27. The tread design or directional pattern of both tire sizes was the same, and is shown in fig. 1. It was understood that this pattern had good self-cleaning qualities when going forward, but poor cleaning qualities when going in reverse. During the tests in fine-grained soils when the wheels began to develop considerable slip, it was noted that mud accumulated between the treads regardless of direction of travel, as shown in fig. 14. However, if the vehicle was moving in either direction with very little wheel slip, very little mud accumulated.

a. Tire tread with no wheel slip

b. Tire tread with considerable wheel slip

Fig. 14. Tire treads before and after mud accumulation and wheel slip

Conclusions and Recommendations

Conclusions

28. Based on results of the tests conducted, the following conclusions are offered:

- a. The experimental VCI for the GOER in fine-grained soils was somewhat higher than computed VCI on the basis of 40 to 50 passes. However, on the basis of 25 passes, closer agreement resulted, especially for the GOER with 18.00-26 tires.
- b. In both fine-grained soils and clean sand the GOER performed better when equipped with the 18.00-26 10-PR tires than when equipped with the 15.00-34 10-PR tires.
- c. The GOER was found to have better soft-ground-crossing abilities than standard 2-1/2-ton and 5-ton 6x6 trucks in the military system.
- d. The GOER has higher drawbar-pull ability (in percentage of test weight) in one specific clean sand condition than any other wheeled vehicle tested to date.

Recommendations

29. Based on test results and the conclusions, it is recommended that:

- a. Trafficability tests be conducted with the 5-ton GOER on several sand conditions, in soft snow, and in muskeg.
- b. Trafficability tests be conducted with a 15-ton GOER.
- c. Additional tests be made of vehicles with large-diameter tires to determine if modification of the mobility index formula for wheeled vehicles is needed.
- d. Tests be made to determine the effect of wide, flat pans on the underbody of wheeled vehicles on the performance of the vehicles on soft ground.

Table 1

Summary of Results of Tests in Fine-Grained Soils

Test Soil	Test No.	Immobilization Data: Yes or No	Immobilization Data: On Pass No.	Pass No.	Cone Index	Soil Data, 6- to 12-in. Depth: Remolding Index	Rating Cone Index	Water Content % Dry Wt	Dry Density lb/cu ft	Rut Depth in.	Remarks
						18.00-26 10-PR Tires (Tire Pressure, 18 psi)					
Silt	1	Yes	14	0	128	0.37	47	35.2	82.3		Dragged slightly on 7th pass. Immobilized on 14th pass in reverse; was able to move forward 10 ft with high slip
				1	80					2	
				5	109					8	
				10	---					23	
	2	Yes	12	0	90	0.47	42	36.5	83.2		Immobilized on 10th pass in reverse; was able to move forward on 11th pass; backed up on 12th pass, again immobilized. Inched forward with extremely high slip
				1	79					3	
				5	103					9	
				10	---					23	
	3	Yes	50	0	154	0.36	55	35.2	82.6		Made no ruts on 1st pass. Developed considerable slip on 40th pass. Ground speed on 45th pass was approximately 0.15 mph. Immobilized in reverse on 50th pass
				1	131					0	
				5	102					3	
				15	135					9	
				50	---					17	
	4	Yes	28	0	130	0.36	47	34.2	85.0		Immobilized on 28th pass going forward; was able to back up 16 ft, but again became immobilized
				1	102					1	
				5	144					5	
				15	153					12	
				28	---					23	
	5	Yes	21	0	149	0.34	51	33.1	86.3		Undercarriage dragged on 15th pass. Became immobilized on 21st pass
				1	115					1	
				15	67					9	
				21	---					29	
	6	No		0	154	0.49	75	34.0	82.9		Completed 50 passes; however, undercarriage was dragging slightly
				1	91					1	
				15	102					11	
	7	No		0	148	0.43	64	34.3	83.2		Completed 50 passes. Undercarriage was dragging between 20th and 50th pass
				1	112					1	
				15	89					7	
	8	No		0	144	0.38	55	35.6	80.6		Completed 50 passes. Considerable wheel slip between 40th and 50th pass
				1	100					1	
				15	87					9	
				50	70					14	
	9	Yes	47	0	129	0.42	54	29.4	88.6		Undercarriage began dragging on 15th pass. Considerable wheel slip after 30 passes. Immobilized on 47th pass
				15	75					8	
	10	No		0	166	0.42	70	33.6	83.7		Completed 50 passes with slight dragging
				15	80					5	
Silty clay	11	Yes	33	0	55	0.70	38	37.8	77.6		Dragged slightly on 12th pass; developed high slip on 25th pass; and was immobilized on 33d pass
				1	72					3	
				10	81					9	
	12	No		0	76	0.66	50	41.8	72.2		Dragged on 38th pass; developed high slip on 40th pass; completed 50 passes with high slip
				1	82					3	
				10	102					6	
	13	No		0	81	0.73	59	40.8	78.8		Undercarriage dragged on 28th pass; however, vehicle completed 20 passes with little wheel slip
				10	89					5	
				50	114					14	
	14	No		0	95	0.68	65	39.0	80.2		Completed 50 passes with ease. Some dragging of undercarriage in soft portion of test lane
				10	84					3	
				50	127					12	
	15	Yes	31	0	68	0.64	44	39.8	77.8		Undercarriage dragged entire lane on 25th pass. Developed high slip on 28th pass. Immobilized on 31st pass traveling forward
				1	71					3	
				20	76					14	
	16	Yes	19	0	51	0.57	29	40.4	76.4		Immobilized on 19th pass traveling forward
				1	67					3	
				10	74					12	
Sandy clay	17	Yes	1	0	113	0.12	14	33.0	83.8		Immobilized on 1st pass when initially firm soil failed quickl. beneath vehicle
				1						24	

(Continued)

Table 1 (Concluded)

Test Soil	Test No.	Immobilization Data: Yes or No	Immobilization Data: On Pass No.	Pass No.	Cone Index	Remolding Index	Rating Cone Index	Water Content % Dry Wt	Dry Density lb/cu ft	Rut Depth in.	Remarks
					Soil Data, 6- to 12-in. Depth						
					15.00-34 10-PR Tires (Tire Pressure, 18 psi)						
Silt	18*	Yes	16	0	122	0.46	56	35.7	83.6		Undercarriage dragged on 10th pass; became immobilized on 16th pass because of some slipperiness but mainly excessive sinkage
				1	111					1	
				15	85					16	
	19*	Yes	11	0	158	0.36	57	37.6	82.0		Undercarriage dragged on 9th pass. Immobilized going forward on 11th pass
				1	116					1	
				10	63					10	
	20*	Yes	14	0	155	0.36	56	32.2	84.0		Undercarriage dragged on 10th pass. Immobilized going backward on 14th pass
				1	117					1	
				10	82					9	
	21*	Yes	17	0	125	0.31	39	39.7	79.6		Undercarriage dragged on 15th pass. Immobilized going forward on 17th pass
				1	113					2	
				10	94					11	
	22*	Yes	13	0	138	0.45	62	34.9	81.7		Undercarriage dragged on 9th pass. Immobilized going forward on 13th pass
				1	92					1	
				10	90					13	
	23	No		0	136	0.50	68	33.6	82.1		Dragged entire lane on 35th pass. Completed 50 passes with considerable wheel slip
				15	73					6	
				50	64					16	
	24	No		0	142	0.52	74	35.2	81.9		Torque converter overheated on 40th pass, but vehicle could have completed 50 passes
	25	No		0	163	0.51	83	33.4	83.7		Undercarriage dragged on 40th pass. Completed 50 passes
				50	84					16	
	26	No		0	153	0.40	61	33.5	85.1		Undercarriage dragged on 30th pass. Completed 50 passes with high slip during final passes
				5	119					4	
				50						18	
	27	No		0	135	0.48	65	33.2	86.3		Completed 42 passes with ease, could have made 50 passes
				5	140					3	
				20	97					11	
	28	Yes	32	0	134	0.38	51	34.2	84.8		Undercarriage dragged on 20th pass. Immobilized on 32d pass in reverse
				5	85					4	
				20	107					14	
	29**	Yes	30	0	144	0.51	73	33.2	84.9		Test conducted during rain. Vehicle immobilized on 30th pass due to slipperiness
	30	No		0	148	0.50	74	31.0	84.4		Undercarriage dragged on 25th pass. Completed 50 passes with ease
				10	114					4	
				50	75					13	
	31	No		0	122	0.47	57	34.8	81.0		Undercarriage dragged on 28th pass. Completed 50 passes with ease
				10	74					4	
				50	66					15	
	32	No		0	138	0.47	65	31.6	84.7		Completed 50 passes with ease
				10	82					5	
				50	77					16	
	33	No		0	166	0.49	81	34.4	81.7		Torque converter overheated on 43d pass, but vehicle could have completed 50 passes
				10	80					6	

* Free water on surface of test lane.
** Free water on surface of test lane and in ruts.

Table 2

Summary of Test Results in Coarse-Grained Soils (Clean Sand)

Test No.	Tire Pressure psi	Maximum Drawbar Pull lb	Maximum Drawbar Pull % of Test Wt	Before-Traffic Soil Data at 0- to 6-in. Depth: Cone Index	Moisture Content % of Dry Wt	Dry Density lb/cu ft
			18.00-26 10-PR Tires			
1	30	7,413	27.8	143	3.2	93.8
2		6,773	25.4	113	6.8	91.6
3		6,227	24.1	119	2.5	92.4
4		7,307	27.4	132	3.6	94.9
5		6,960	26.1	140	3.5	98.6
6		7,120	26.7	143	9.2	84.7
7		7,147	26.8	126	8.6	93.5
8	20	8,933	33.5	151	---	--
9		9,200	34.5	151	5.3	94.3
10		8,133	30.5	136	---	--
11		8,533	32.0	126	---	--
12		8,720	32.7	134	7.3	95.6
13		8,667	32.5	135	---	--
14	15	10,133	38.0	157	---	--
15		10,347	38.8	146	3.7	95.8
16		10,667	40.0	136	---	--
17		9,973	37.4	142	---	--
18		9,760	36.6	147	---	--
19		9,760	36.6	144	5.2	90.6
20	10	11,493	43.1	126	3.0	92.8
21		11,920	44.7	145	---	--
22		11,840	44.4	141	---	--
23		11,413	42.8	149	---	--
			15.00-34 10-PR Tires			
24	30	6,400	24.0	135	6.0	94.0
25		6,667	25.0	132	3.4	93.0
26		6,427	24.1	134	3.1	94.2
27		6,613	24.8	144	7.8	91.3
28		6,267	23.5	142	3.3	95.0
29		6,907	25.9	144	3.9	90.1

(Continued)

Table 2 (Concluded)

Test No.	Tire Pressure psi	Maximum Drawbar Pull lb	Maximum Drawbar Pull % of Test Wt	Before-Traffic Soil Data at 0- to 6-in. Depth: Cone Index	Moisture Content % of Dry Wt	Dry Density lb/cu ft
			15.00-34 10-PR Tires (Continued)			
30	20	8,347	31.3	130	---	--
31		8,240	30.9	136	4.3	91.6
32		8,293	31.1	130	---	--
33		8,213	30.8	123	3.8	93.4
34		8,160	30.6	130	---	--
35		8,000	30.0	130	---	--
36		8,080	30.3	129	3.5	91.6
37	15	9,493	35.6	145	3.2	88.2
38		9,493	35.6	143	---	--
39		9,440	35.4	134	3.7	94.2
40		9,573	35.9	148	---	--
41		9,333	35.0	141	3.7	91.2
42		9,387	35.2	141	---	--
43		9,307	34.9	136	---	--
44		9,280	34.8	139	3.8	94.8
45	10	11,387	42.7	151	7.2	89.5
46		11,333	42.5	146	---	--
47		10,907	40.9	139	---	--
48		10,960	41.1	129	2.9	90.9
49		10,400	39.0	126	---	--

APPENDIX A: DETERMINATION OF VEHICLE CONE INDEX FOR THE 5-TON GOER FOR OPERATION ON FINE-GRAINED SOILS

1. The determination of vehicle cone index for the 5-ton GOER is described in detail in the following paragraphs. The first step in this determination is derivation of the mobility index.

Mobility Index

2. The mobility index is a number obtained by applying vehicle "factors" in the following formula for self-propelled wheeled vehicles.

$$\text{MI} = 0.6\left[\left(\frac{\begin{matrix}\text{contact}\\ \text{pressure}\\ \text{factor}\end{matrix} \times \begin{matrix}\text{weight}\\ \text{factor}\end{matrix}}{\begin{matrix}\text{tire}\\ \text{factor}\end{matrix} \times \begin{matrix}\text{grouser}\\ \text{factor}\end{matrix}} + \begin{matrix}\text{wheel}\\ \text{load}\end{matrix} - \begin{matrix}\text{clearance}\\ \text{factor}\end{matrix}\right) \times \begin{matrix}\text{engine}\\ \text{factor}\end{matrix} \times \begin{matrix}\text{trans-}\\ \text{mission}\\ \text{factor}\end{matrix}\right] + 20$$

Vehicle Factor	Value
GOER Equipped with 18.00-26 10-PR Tires	
Contact pressure factor $= \dfrac{\text{gross weight, lb}}{\left(\begin{matrix}\text{nom tire}\\ \text{width, in.}\end{matrix}\right)\left(\begin{matrix}\text{rim}\\ \text{diam, in.}\end{matrix}\right)\left(\begin{matrix}\text{No. of}\\ \text{tires}\end{matrix}\right)} =$ $\dfrac{26{,}667}{18 \times 26 \times 4}$	= 14.25
Weight factor: 15,000 to 35,000 lb	= 1.00
Tire factor $= \dfrac{1.25 \times \text{nom tire width, in.}}{100} = \dfrac{1.25 \times 18}{100}$	= 0.225
Grouser factor: without chains	= 1.00
Wheel load $= \dfrac{\text{gross weight, kips}}{\text{No. of wheels}} = \dfrac{26.7}{4}$	= 6.67
Clearance factor $= \dfrac{\text{clearance, in.}}{10} = \dfrac{21}{10}$	= 2.10
Engine factor: $< \dfrac{10\ \text{hp}}{\text{ton}} : \dfrac{110}{13.35} = \dfrac{8.24\ \text{hp}}{\text{ton}}$	= 1.05

(Continued)

Vehicle Factor		Value
GOER Equipped with 18.00-26 10-PR Tires (Continued)		
Transmission factor: torque converter	=	1.00
$\mathrm{MI} = 0.6 \left[\left(\frac{14.25 \times 1.00}{0.225 \times 1.00} + 6.67 - 2.10\right) \times 1.05 \times 1.00\right] + 20$	=	62.8
GOER Equipped with 15.00-34 10-PR Tires		
$\text{Contact pressure factor} = \frac{\text{gross weight, lb}}{\left(\text{nom tire width, in.}\right)\left(\text{rim diam, in.}\right)\left(\text{No. of tires}\right)}$	=	
$\frac{26{,}667}{15 \times 34 \times 4}$	=	13.07
Weight factor: 15,000 to 35,000 lb	=	1.00
$\text{Tire factor} = \frac{1.25 \times \text{nom tire width, in.}}{100} = \frac{1.25 \times 15}{100}$	=	0.187
Grouser factor: without chains	=	1.00
$\text{Wheel load} = \frac{\text{gross weight, kips}}{\text{No. of wheels}} = \frac{26.7}{4}$	=	6.67
$\text{Clearance factor} = \frac{\text{clearance, in.}}{10} = \frac{22}{10}$	=	2.20
$\text{Engine factor:} < \frac{10\ \text{hp}}{\text{ton}} : \frac{110}{13.35} = \frac{8.24\ \text{hp}}{\text{ton}}$	=	1.05
Transmission factor: torque converter	=	1.00
$\mathrm{MI} = 0.6 \left[\left(\frac{13.07 \times 1.00}{0.187 \times 1.00} + 6.67 - 2.20\right) \times 1.05 \times 1.00\right] + 20$	=	66.8

3. The mobility indexes have been correlated with minimum strength requirements for conventional military vehicles in fig. A1.

Vehicle Cone Index

4. The vehicle cone index is the term applied to the minimum

strength required in the critical soil layer for a vehicle to complete 40 to 50 passes. Through correlations between mobility index and test results, the curve shown in fig. A1 can be used to determine the vehicle cone index after the mobility index has been computed. From the curve it can be seen that the GOER has a computed vehicle cone index of 54 when equipped with the 18.00-26 tires, and 56 when equipped with the 15.00-34 tires.

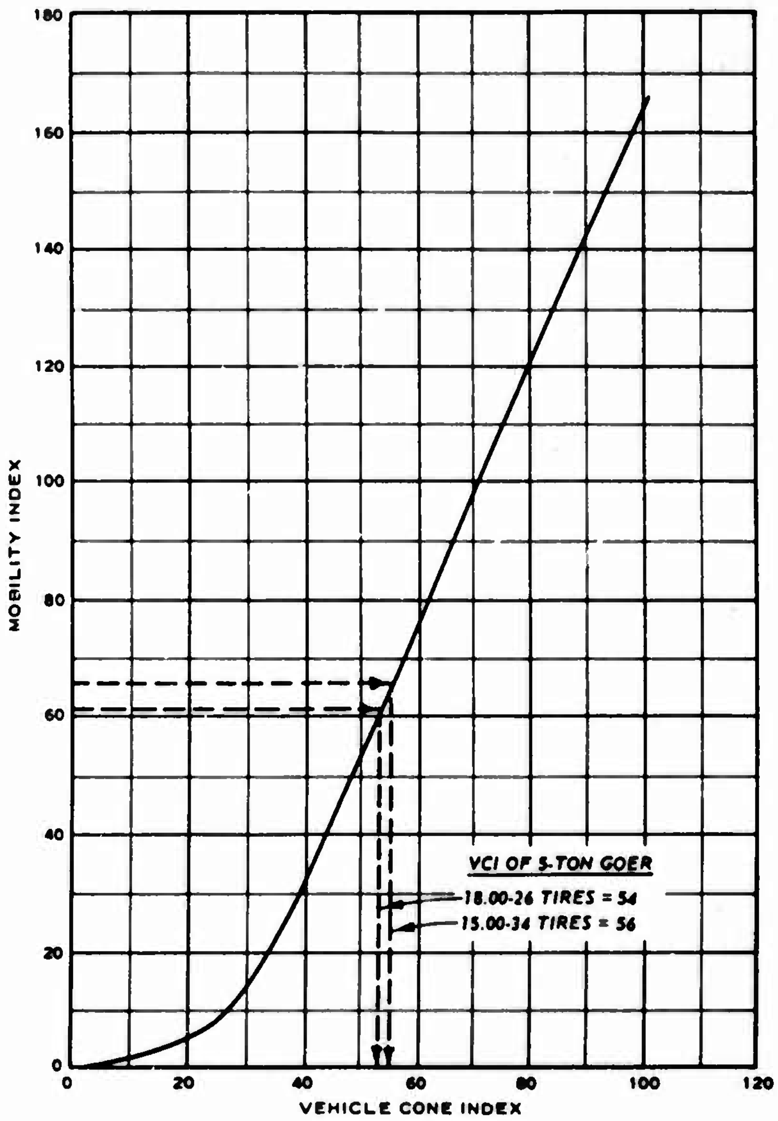

Fig. A1. Vehicle cone index vs mobility index